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ENERGY SECURITY: INVESTIGATING ANAEROBIC DIGESTION FOR AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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ABSTRACT

The environmental impact of waste is a growing global concern. Its contribution to global warming via methane emissions being released into the atmosphereis relatively more intense than coal-fired power stations through carbon-dioxide emissions on a unit for unit basis. Sites that have daily high human occupancy rates such as airports produce significant volumes of ablution waste, kitchen sink run-off, storm water and wastewater from other commercial and operational activities including car washes, aircraft ablutions wash off, etc. It can become costly to install, operate and maintain wastewater treatment plants in the instance when the local municipal waste water treatment works are not able to accommodate sewage capacity produced by the site as in the case of King Shaka International Airport in South Africa. The more common practice for airport sewage design is to construct holding tanks and release to municipal works when these tanks reach a certain level. This infrastructure is costly to install and maintain. Failure in any of the mechanisms of timeously releasing sewage is very inconvenient to airport operations. Processing this waste for the purposes of producing methane rich fuel gas for power production and using the digestate as fertilizer while making available second-class water to reduce potable water demand as the potential to solve the multiple challenge of greenhouse gas emissions and conserve potable water. This paper presents the technical and financial evaluation (pre-feasibility) or techno economic assessment of using waste from airports in South Africain ananaerobic digestion process producing methane gas to be used as fuel for energy.

KEYWORDS: Techno-Economic Assessments, Renewable Energy, Alternative Energy, Feasibility of Renewable Energy, Anaerobic Digestion, Biogas Generation & Reuse of Treated Effluent

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Original Article

1. INTRODUCTION

Many countries are awaking to the reality that waste is a serious threat not just due to global warming, but also because of the resulting contaminated water sources. Due to this, many countries are imposing restrictions and legislations that drive waste re-use and repurposing. Many countries have strict rules in place for organizations producing toxic waste, such as chemical and solid by-products of industrial processes that protect water quality and preserve natural habitats. Where wastewater spillage occurs or industrial chemical spills occur, the clean-up and rehabilitation of contaminated land is costly and there is never a guaranteed zero impact from the clean up or rehabilitation.

With population growth in the age of consumerism and urbanization, there is a growing need for landfills and there is the challenge of protecting water quality as more people have access to indoor plumbing, and every product sold has packaging and short use. There is a need for innovative thinking around sustainably solving these problems. Airports are like mini-cities in that they provide retail, food and beverage services, accommodation,

travel networks and transport services, fuelling stations, postal and cargo services. They are centres where high waste volumes are produced, both wet waste or sewage and dry or solid waste. Operational cost and maintenance costs are high.

Negating the need for costs associated with disposing of sewage, including the cost of infrastructure associated with conveying the sewage to the municipal works, by using the waste to generate energy, is a possibility that can be considered for OR Tambo International Airport, Cape Town International Airport and King Shaka International Airport. King Shaka International Airport has a Wastewater Treatment Plant (WWTP) onsite built for the airport's sewage processing which is maintained and operated by the airport. Monthly disposal costs of sludge and wastewater when they donot meet specific criteria to be released into natural streams are high. Cape Town International Airport and OR Tambo International Airport have holding tanks for the sewage generated by the airport after which, having reached a certain level, it is transferred to the municipal water treatment works via a bulk sewer pipeline.

In the course of looking at waste as a potential revenue stream as opposed to an operational cost, anaerobic digestion was considered and evaluated for the three larger international airports within the Airports Company South Africa group of nine airports. The waste volumes at the other airports within the group was not large enough or consistently enough replenished to be considered for anaerobic digestion. Solid waste was initially considered, however, since the generation of carbon-dioxide on-site from incinerating the waste material will go against the goal of decreased carbon footprint, it was decided that an increase in recycling be the focus rather than energy generation.

Airports Company South Africa is South Africa's airport authority in South Africa owning and operating nine airports, namely, O R Tambo International Airport (ORTIA) (Kempton Park, Gauteng), Cape Town International Airport(CTIA) (Western Cape), King Shaka International Airport (KSIA)(Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

This techno economic assessment focuses largely on the economics of utilizing sewage (and food waste) for the generation of biogas through anaerobic digestion (AD) based on sewage waste volumes and characterization of the food waste at KSIA, and the sewage streams at CTIA. The economics presented here provides direction on whether anaerobic digestion is worth further investigation. The study also presents the dynamics surrounding the needs and benefits of anaerobic digestion which are in addition to biogas production for energy generation. The study covers the technology description, technology types and typical plant equipment, the assessment of technology maturity, the cost-benefit analysis with financial indicators, technology risk assessment, airport integration strategy, proposed operational philosophy and concludes by proposing future steps.

The key parameters for the waste stream to be suitable for anaerobic digestion are:

- Chemical oxygen demand (COD) limits. COD is used to quantify the amount of organic matter in waste streams and predict the potential for biogas production. The oxygen equivalent of organic matter that can be oxidised, is measured using a strong chemical oxidising agent in an acidic medium. During anaerobic digestion, the biodegradable COD present in organic material is preserved in the end products, namely methane and the newly formed bacterial mass. For domestic sewage, typical COD is between 550 mg/L to 700 mg/L.
- Carbon-nitrogen ratio of the input material, optimum ratio of C:N is 20-30:1; excess nitrogen will lead to the

production of ammonia which will inhibit the digestion process.

- Optimum pH level of 6.8 to 7.2 (6.5 to 8.0 is tolerable).
- The degree of contamination with plastic, glass and metals will require more mechanical processing and thus increase capital costs. For domestic sewage, the degree of contamination is between 250 mg/L to 400mg/L.

The key parameters for the success of the AD process are:

- Feedstock characterization.
- Operational conditions.
- Temperature – Optimum temperature of a mesophilic digester is 35°C An acceptable range, although with decreased production, is 10°Cto 37°C. The optimum temperature range for athermophilic digester is 55°C to 60 °C.
- pH and alkalinity – 6.5 to 8.0 is an acceptable range.
- Toxicity is undesirable, although not entirely avoidable.

The key parameters for anaerobic digestion to be adopted are:

- It should have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Risks should be acceptable.
- It should have a local footprint for technical support with operationally acceptable response times.

2. DESCRIPTION OF THE TECHNOLOGY

AD is the natural process in which complex organic materials are broken down into simpler compounds in the absence of oxygen by the action of several micro-organism communities. AD consists of four biochemical steps: hydrolysis where hydrolytic bacteria remove polymers to monomers; acidogenesis where acidogenic bacteria remove monomers to short carboxylic acid, carbon dioxide, hydrogen and alcohol; acetogenesis where the products of the previous phase are removed to acetic acid and methanogenesis where methane is built of the acetic acid [1]. figure 1 and figure 2 present the processs chematically.

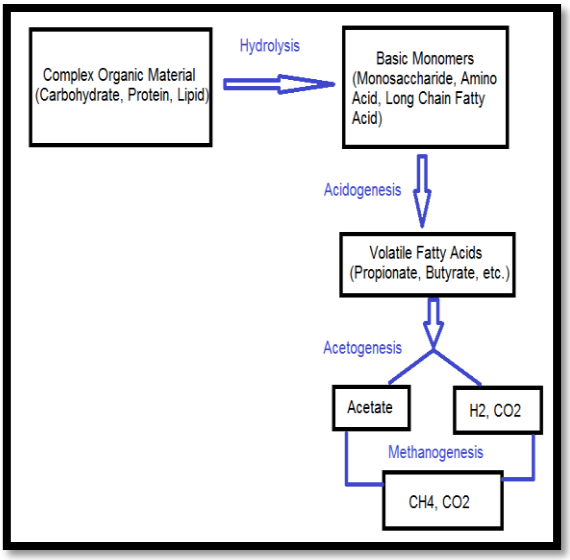


Figure 1: Anaerobic Digestion Process Producing

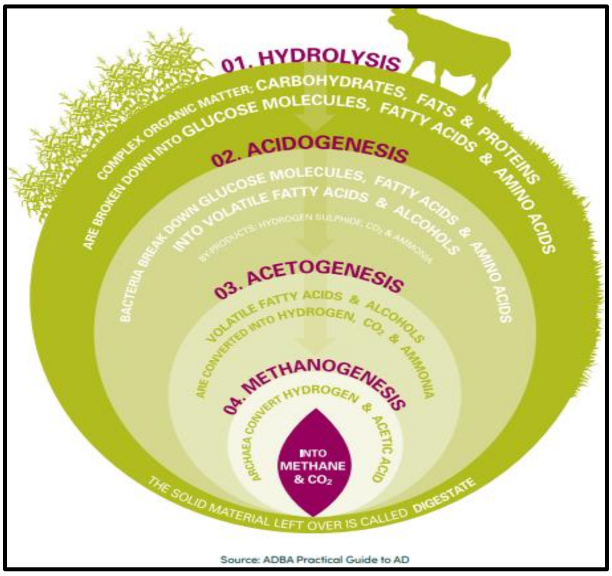


Figure 2: Anaerobic Digestion [2] Methane (CH4).

The key benefit of the AD process is the production of biogas, a renewable energy source, which can be used as fuel for the internal combustion engines, for direct heating and, in cogeneration, for electricity production as well.

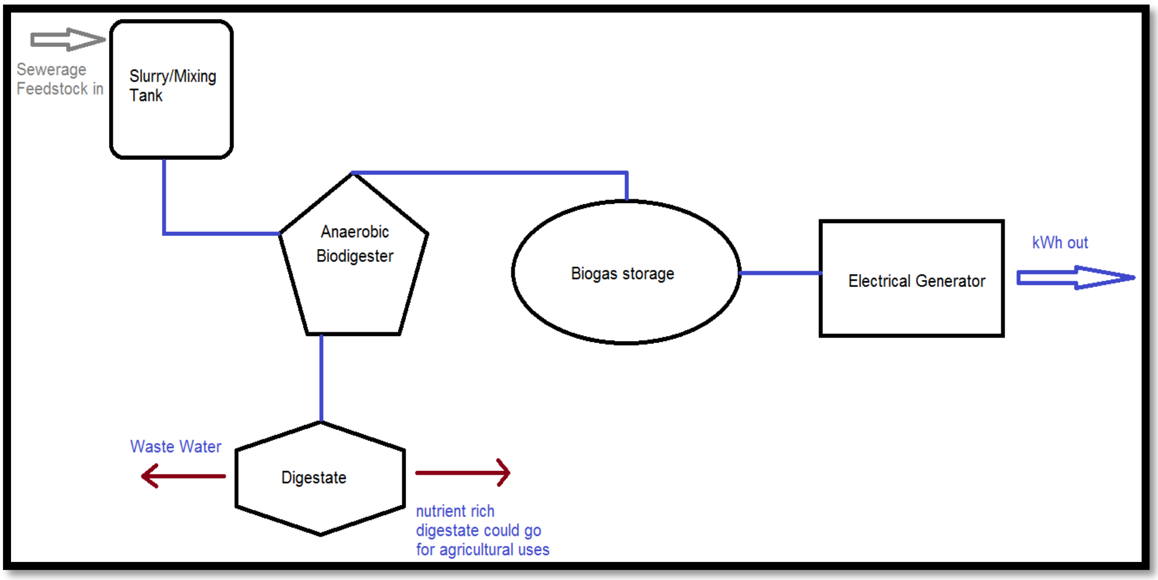


Figure 3: Simplified Plant Schematic for the Anaerobic Digestion Process.

The feedstock is anaerobically digested in a biodigester where the methane gas product is captured and stored until it is combusted in a combustion engine, turning the shaft of an electrical generator and thus producing electricity. Figure 3 shows the process schematically. Other products produced in the AD process are the digestate containing mineralized remains of dead bacteria, and lignin and cellulose suspended in water. This could be used for agricultural purposes.

The purpose of the slurry or mixing tank shown in Fig. 3 is to break down the organic matter prior to it entering the biodigester/reactor. This is called a continuous process. In the alternative, which is a batch process, the biodigester is

fed with feedstock at the start of the process and then sealed for the duration of the AD process.

AD takes place at two optimum temperature ranges, 35°C to 40°C (mesophilic) and 55°C to 60°C (thermophilic). Most AD plants around the world operate in the mesophilic range as less heat is required to maintain that temperature and the digestion process is more stable under these conditions. Thermophilic reactors, although requiring greater attention to operate, are sometimes installed as they accelerate degradation rates and create higher yields of biogas and reduce pathogens in the digestate produced. Based on the constituents and consistency of the food waste treated, an AD can be designed as a 'wet', 'dry', 'liquid' or 'co-digestion' system [2]. Fig.4 provides information about the configurations.

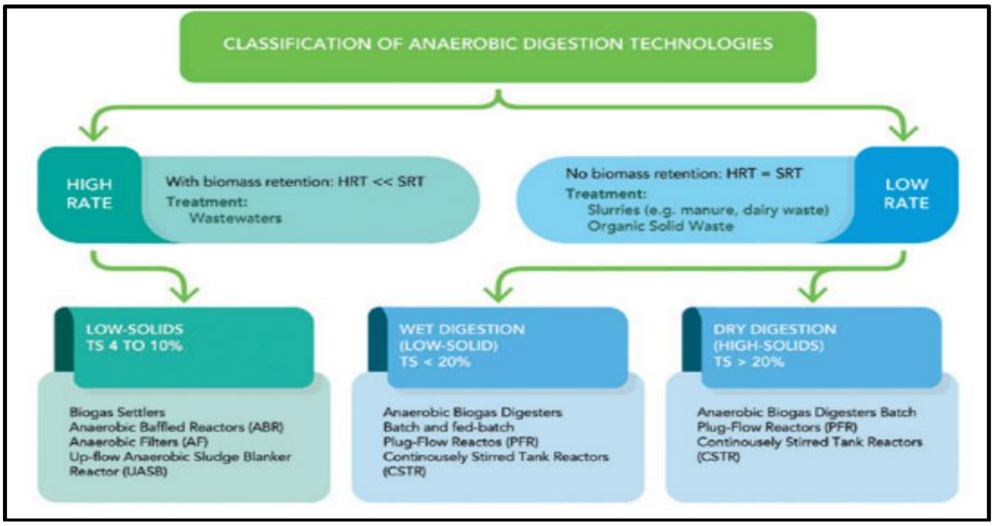


Figure 4: Anaerobic Digestion Technologies [2]

The classification of anaerobic digestion technologies is divided into high rate and low rate. The high rate has low solids (4 % to 10 %) with biomass retention where the solids retention time (SRT) is much higher than the hydraulic retention time (HRT).This is characteristic of wastewater treatment. The low rate has no biomass retention, i.e., the HRT and SRT are equal. This is characteristic in slurry treatment (such as manure and dairy waste) and organic solid waste. The low-rateAD technologies are further classified into wet digestion where the solid content is less than 20%,and dry digestion where the solid content exceeds 20%. [2]

The HRT is the amount of time in hours for wastewater to pass through a tank, such as an aeration tank. Changes in the HRT of an activated sludge process (slurry or mixing tank as in Fig. 3 which introduces air into the sewage feedstock) can affect biological activity. For example, decreasing HRT adversely affects nitrification, while increasing HRT favours nitrification and the solubilization of colloidal biochemical oxygen demand (BOD) and particulate BOD. BOD is the amount of oxygen required to chemically breakdown the pollutants biologically through micro-organisms. The mean cell residence time (MCRT) is the amount of time, in days, that solids or bacteria are maintained in the activated sludge system. The MCRT is known also as the solids retention time (SRT). To calculate the MCRT of an activated sludge process, it is necessary to know the amount (in kilograms) of solids or suspended solids in the activated sludge system and the amount (in kilograms) of suspended solids leaving the activated sludge system [3].

A biogas plant has a reception area where the feedstock from various sources is received. The wastere sides in the reception area for some hours whilst it is loaded into the next stage: pre-treatment. This next stage generally involves washing, maceration of the feedstock, screening and pressing depending on the feedstock. Packaging, such as plastic bags,

is stripped out, while any metallic items such as cutlery may be removed using magnetic devices to prevent damage to moving parts. In addition, grit (such as glass, eggshells, ceramics, bones and sand) may need to be removed at the pre-treatment stage if the digester doesnot have the internal capability of extracting these. If not removed, grit may build up at the bottom of the tank over a period of time leading to loss of volume and failure of the system [2].

After the pre-treatment process, the feedstock is fed to the digester where it undergoes decomposition in the absence of oxygen. This process can take place at different operating temperatures and system setups. During this process, biogas is released and collected in biogas storage tanks or in an inflatable dome. To reduce the sulphur content in biogas, it is piped to a desulphurisation unit. The biogas, which is rich inmethane, may be processed further depending upon the desired end use such as electricity, heating, cooling or vehiclefuel. Within the digester, the organic material that is left over after digestion, or digestate, is extracted and may then undergo pasteurisation, followed by composting or separation of wet and dry solids for application to agricultural land, depending on the use and regulations of the jurisdiction. [2]

Drier, stackable substrates, such as food and yard waste, are suitable for digestion in tunnel-like chambers. Tunnel-style systems typically have near-zero wastewater discharge as well, so this style of system has advantages where the discharge of digester liquids is a liability. The wetter the material, the more suitable it will be for handling with standard pumps instead of energy-intensive concrete pumps and physical means of movement. Also, the wetter the material, the more volume and area it takes up relative to the levels of gas produced. A typical plant layout that treats urban sewage can be seen in figure. 5 showing the digesters and gas storage tank as indicated in the plant layout in figure 3.

Figure 5: An on-Farm Anaerobic Digester Plant Showing the Gas Storage Tank and Digesters [2].

The biodigester/reactor design is based on the intended operational need for electricity/heating, the feedstock constituents and flow rate and the climatic or environmental conditions. The control of temperature, pH, toxicity and other parameters in the process depends on the feedstock characterization and climatic conditions. The chemical equation for anaerobic digestion can be seen in Equation 1and the corresponding biogas composition can be seen in Table 1.

$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$………………………………………………………………. Equation 1

Table 1: Typical Composition of Biogas [4]

Compound	Formula	%
Methane	CH_4	55 to 65
Carbon dioxide	CO_2	35 to 45
Carbon monoxide	CO	0 to 3
Nitrogen	N_2	0 to 1
Hydrogen	H_2	0 to 1
Hydrogen sulphide	H_2S	0 to1
Oxygen	O_2	0 to2

Figure 6 shows the anaerobic bioprocess performance in the anaerobic membrane bioreactor (AnMBR). The AnMBR is a wastewater treatment technology that combines anaerobic suspended-growth biological treatment with membrane filtration. AnMBRs will likely play a significant role in wastewater treatment in the future as the anaerobic process has low energy and nutrient requirements, lowsludge production and can generate biogas that can be directly employed as an energy source. The use of membranes for biomass separation can provide long solid retention times (SRTs) which are required to offset the low growth rates of anaerobic organisms while also producing a solids-free effluent [5].

Type of Municipal WW	Scale/ Membrane module	Type of Reactor[a]	Volume (L)	Operation Time (day)	Temp (°C)	SRT (d)	HRT (h)	Digester TSS (g/L)	Effluent COD (mg/L)	Biogas Production	Reference
Municipal WW COD:280~360mg/L	Bench/ Hollow Fiber	(IAFMBR)	5.8	160	35	-	8, 6, 4	-	13, 22,50	0.14~0.19L CH_4/g COD	Gao et al., 2014
Municipal WW COD:366~486mg/L	Bench/ Hollow Fiber	CSTR	6	40	25~30	30,60,90	10	8.0,12.6,12.7	47~73 (No impact by SRT)	0.04, 0.09, 0.10L CH_4/g COD	Huang et al., 2013
Synthetic (COD 513mg/L)	Bench/ Hollow Fiber	Upstream anaerobic bioreactor+AFMBR	10.64	120	35	-	4.2-5	11.6(TSS)	3~11	0.17LCH_4/g COD	Kim et al., 2011
Synthetic (COD 550 mg/L)	Bench/ plate and frame	CSTR	6	150	25~30	30,60, infinite[b]	8,10,12	5.5-10.5	5.5~16.5	0.12~0.25 L CH_4/g COD	Huang et al., 2011
Pre-settled Sewage (sCOD 38~131)	Bench/ -	CSTR	10	440	-	19~217	12~48	1~7	sCOD 14~51	No gas production	Baek et al., 2010
Synthetic (OLR1~2kg/m3/d)	Bench/ Tubular	CSTR	4	270	25	90~360	6~12	6~11	10~40	0.22L CH_4/gCOD	Ho and Sung., 2009
Municipal WW (0.5mm screened COD: 350~540mg/L)	Full/Hollow Fiber	CSTR	2100	140	33	70	6~21	8~22	44~100	0.069L CH_4/gCOD	Gimenez et al., 2011
Pre-settled Sewage (COD 540mg/L)	Bench/Hollow fiber	CSTR	180	365	25	-	4.5, 6, 12	14~80 (TS)	65	-	Lew et., al 2009
Synthetic (COD 440~480 mg/L)	Bench/Hollow fiber and flat sheet	CSTR	3	100	35	-	48,24,12,6,3	Around 4 (TSS)	<50 (COD increasing with HRT decreasing)	0.22~0.33L CH_4/gCOD	Hu and Stuckey., 2006
Municipal WW (COD: 337~459mg/L)+ glucose=total COD (548~712)	Pilot/flat sheet	CSTR	350	100	35	-	~16.5	15	COD<80 BOD<25	0.2~0.25L CH_4/gCOD	Martinez-Sosa et al.,2011
Synthetic (COD340~260 mg/L)	Bench/tubular	UASB	12.5	-	-	-	4,8,12	-	40~65, (COD increasing with HRT decreasing)	-	Salazar-Peláez, et al., 2011

a: IAFMBR:Integrated anaerobic fluidized-bed membrane bioreactor AFMBR indicates anaerobic fluidized bed bioreactor; UASB: upflow anaerobic sludge blanket reactor; CSTR: completely stirred tank reactor
b: infinite indicates no sludge wasting
-: not indicated

Figure 6: Typical Anaerobic Bioprocess Performance in Ananaerobic Membrane Bioreactorwith Municipal Wastewater (Sewage) as Feedstock [5].

In figure. 6, note the typical COD levels and the biogas yield together with the corresponding SRTs, HRTs and total suspended solids (TSS) parameters. The techno economic assessment uses the sewage from ORTIA, CTIA and KSIA and the food waste from KSIA to determine the suitability for the anaerobic digestion when examining the COD levels and other parameters established in the previous section. A municipal Excel based model is used to simulate the biogas production for this techno economic assessment.

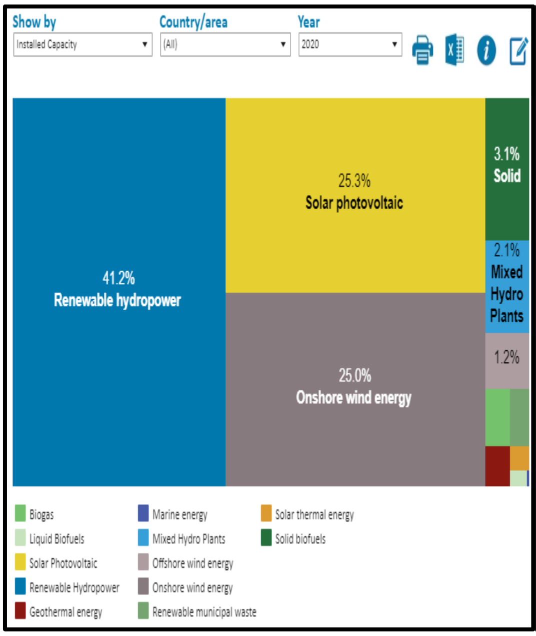
3. ASSESSMENT OF TECHNOLOGY MATURITY

Although there is already a wide application of biogas technologies around the world, the industry is still in its initial stages of development. Micro digesters have been used for at least several centuries. Indeed, if we go back in ancient history, we will find elementary biogas production during the Assyrian Empire 3000 years ago whilst more recognisably modern applications began to develop during the 17th century. Micro digesters play a very important role in rural areas of developing countries, where they are an integral part of farming, waste management and energy security. There is a total of close to 50 million micro-scaledigesters operating around the globe with 42 million [6] operating in China [7]and another 4.9 million in India [8].700000 biogas plants are estimated to have been installed in the rest of Asia, Africa and South America [9][2].

Generation of electricity from biogas is an established technology which has been widely implemented around the globe. This is most commonly done with a combined heat and power (CHP) engine with some form of heat recovery and use. A CHP engine can be linked to any operating anaerobic digester. For it to be economic, a CHP engine requires a minimum size. Operators of biogas plants are trying to maximise efficiency and income streams by increasing the utilisation of heat. There is also a growing interest in trigeneration which generates electricity, heat and cooling when needed. The biogas industry is growing globally. IRENA statistics on global electricity generation from biogas show that it has grown from 46108 GWh in 2010 to 87500 GWh in 2016 [10], a 90% growth in six years [2].

Upgrading of biogas to biomethane is relatively new but is by now a proven technology. While some plants upgrade biogas to be used as vehicle fuel, others inject it into local or national grids. Plants are also beginning to capture carbon dioxide to be used in greenhouses and the food and drinks industry. There are over 540 upgrading plants operating in Europe with 195 in Germany, 92 in the UK, 70 in Sweden, 44 in France, and 13 in the Netherlands [11]. Outside of Europe, there are about 50 in the USA [12], 25 in China [13], 20 in Canada [14] and a few in Japan, South Korea, Brazil and India. Based on the data available, it is estimated that 700 plants globally upgrade biogas to biomethane.

In comparison to other renewable energy technologies installed capacity, global biogas installed capacity as of year 2020is still behind hydropower, solar photovoltaic installations, wind power (onshore and offshore) and solid biofuel technologies. However, its adoption is more popular than geothermal energy, solar thermal energy, liquid biofuels and marine energy technologies. This is shown in Figure. 7. When looking at biogas energy related to ‘renewable municipal waste’ (Figure. 8), China is leading in installed technology capacity, and when looking at biogas technologies (Fig. 9),Germany has the most installed technology capacity followed by the USA and UK.



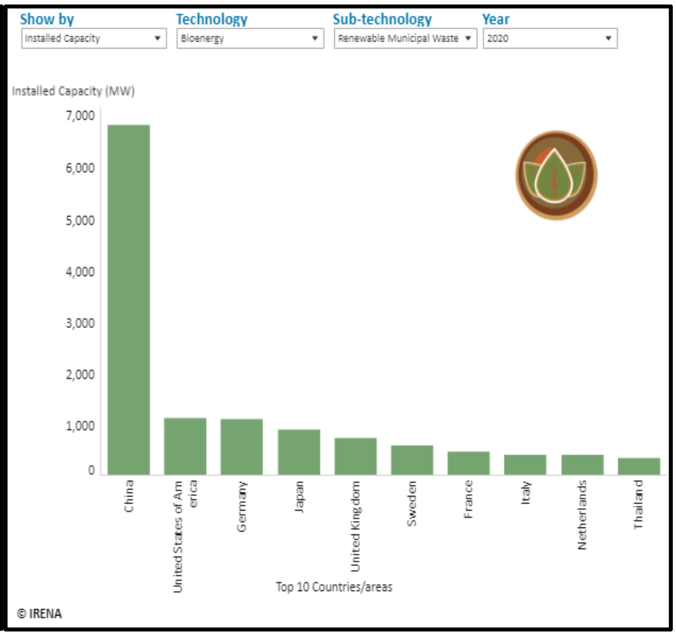
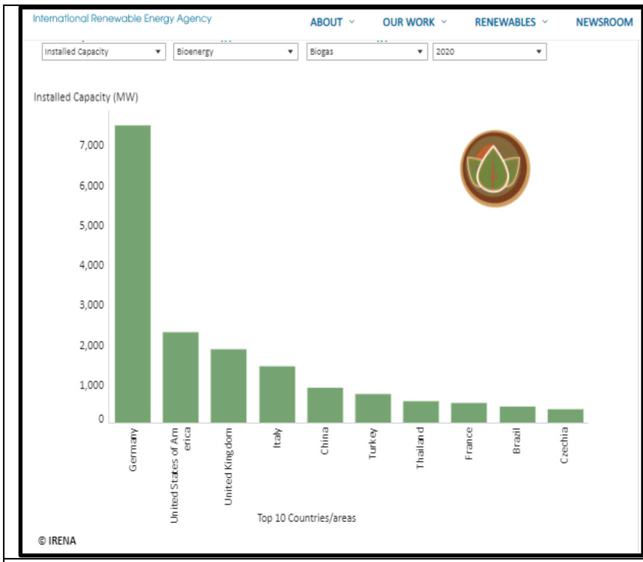


Figure 7: Global Renewable Energy Installed Capacity, 2020 [15]

Figure 8: Top Ten Countries Renewable Municipal Waste Energy Technologies Installed Capacity [16].



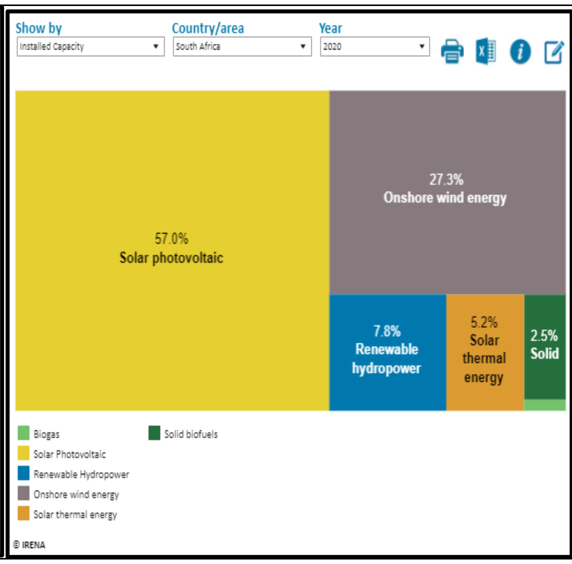


Figure 9: Top Tencountries Biogas Energy Technologies Installed Capacity [16]

Figure 10: Renewable Energy Technologies Installed Capacities in South Africa, 2020 [15].

When looking at South Africa, biogas has the smallest share of installed technology capacity among South Africa's solar photovoltaic, onshore wind, renewable hydropower, solar thermal and solid biofuel energy installed technologies, figure. 10. 9 Figure. 11 shows a biogas demonstration plant installed in Wellington in the Western Cape province of South Africa. Renewable energy and waste disposal solutions provider Global Energy constructed this fully operational biogas demonstration plant using technology that has been designed to be more cost effective, manufactured locally and simpler to operate and maintain [17].

Figure 11: Biogas Demo Plant Installed in the Western Cape, South Africa (2018) [17].

Biogas technologies are established globally and in South Africa. It may not be as widely adopted as other renewable energy sources such as wind, solar, hydro, marine, liquid and solid biofuel. This means that there are established commercial markets and technical support for anaerobic digestion technologies. It may not be as plentiful as other renewable energy technologies, but it is present.

4. COST BENEFIT ANALYSIS

This section summarizes the cost benefit analysis at pre-feasibility and is meant to provide direction as to the financial gains of using anaerobic digestion to generate energy. A pre-feasibility study conducted at the Front-End Loading Stage 2 (FEL 2) is typically performed after a strategy is approved and the necessary technologies and other instruments have been identified for the realization of the strategy. Due to the AD and associated technologies not having been investigated before for ACSA or its airports, it is important to get an indication of the waste quantities and quality of waste streams (waste characterization) with as little investment as possible so as to determine whether AD is suitable for further investment. A feasibility study follows after the pre-feasibility and technology assessment has been completed.

AD of sewage and food waste (referred to as feedstock) for the purposes of airport energy consumption requires a steady production of biogas, which means a steady flow of feedstock. This is characteristic of the three larger airports, namely, ORTIA, CTIA and KSIA. The other airports owned and operated by ACSA do not have steady volumes of feedstock. The volume of sewage output of the three airports can be seen in table 2.

Table 2: Raw Sewage Volumes of ACSA's International Airports

Airport	m^3 of Raw Sewage per Year	m^3/Day of Raw Sewage
OR Tambo International Airport	1 200 000,00	3 287,67
Cape Town International Airport	600 000,00	1 643,84
King Shaka International Airport	400 000,00	1 095,89

At FEL2, it is important to confirm if the airports' sewage streams are suitable for anaerobic digestion process. Confirming key parameters for ORTIA's sewage was costly and it was decided that the waste characterization ofthe other two airports wouldbe sufficient. At KSIA and CTIA the sewage waste was tested for suitability as feedstock in the AD process. KSIA's feed waste was also characterized to determine the possibility of AD. The sampling results of KSIA's onsite North and South Waste-Water Treatment Plant's (WWTP's) raw sewage is included in Table 3. Table 4 shows the sampling results from CTIA's raw sewage which is usually pumped to municipal works. KSIA treats the raw sewage of both North and South WWTP at the South WWTP. The sewage sampling was performed by KSIA's waste service

provider for KSIA's sewage and by an independent lab for KSIA's food waste. The sampling for CTIA's sewage was performed by another independent lab. Table 3: KSIA South and North Waste-Water Treatment Plant results, testing for suitability as feedstock in anaerobic digestion

Table 3

	Sample Number	Date of Sample	Chemical Oxygen Demand (mg/l)	Suspended Solids @ 105°C (mg/l)	Oil and Grease (mg/l)	Electrical Conductivity at 25°C (mS/m)	pH at 25°C	Ammonia (NH3) (mg/l)	Nitrate (NO3) (mg/l)
South Waste-Water Treatment Plant Raw Effluent	1	12/10/2018	1 300,0	734,0	112,0	190,5	7,9	87,9	0,1
	2	20/10/2018	549,0	218,0	64,0	148,8	7,9	56,6	0,9
	3	23/10/2018	952,0	526,0	84,0	204,0	8,6	99,3	0,8
	4	13/11/2018	657,0	-	-	116,3	7,5	48,2	1,1
	5	21/11/2018	896,0	750,0	43,0	171,1	8,2	91,0	1,1
	6	27/11/2018	762,0	348,0	72,0	164,1	7,4	75,3	0,9
	7	04/12/2018	325,0	206,0	-	112,4	7,0	68,0	<0,1
	8	13/12/2018	608,0	420,0	38,0	132,4	8,0	54,0	62,0
	9	19/12/2018	602,0	202,0	-	162,5	7,3	148,0	<0,1
	10	22/01/2019	575,0	512,0	62,0	112,3	7,1	41,8	0,6
	11	31/01/2019	546,0	240,0	44,0	110,2	7,9	41,3	0,4
	12	04/02/2019	672,0	484,0	75,0	113,3	7,4	41,9	0,3
	13	11/02/2019	1 147,0	560,0	110,0	115,8	6,9	31,9	0,4
	14	08/03/2019	855,0	838,0	-	182,1	8,8	17,4	0,7
	15	14/03/2019	676,0	456,0	66,0	143,9	7,6	42,6	0,4
	16	20/03/2019	255,0	112,0	8,0	64,6	8,0	0,5	17,6
	17	25/03/2019	-	-	-	143,8	7,7	53,8	0,7
	18	08/04/2019	751,0	406,0	103,0	125,0	8,4	48,3	0,6
	19	15/04/2019	553,0	286,0	51,0	107,6	7,7	32,1	1,1
	20	25/04/2019	-	-	-	62,9	6,8	10,0	1,0

Table 3 continued

	Sample Number	Date of Sample	Chemical Oxygen Demand (mg/l)	Suspended Solids @ 105 °C (mg/l)	Oil and Grease (mg/l)	Electrical Conductivity at 25 °C (mS/m)	pH at 25°C	Ammonia (NH_3) (mg/l)	Nitrate (NO_3) (mg/l)
North Waste-Water Treatment Plant	21	12/10/2018	704,0	270,0	86,0	111,4	8,8	25,9	0,8
	22	20/10/2018	516,0	248,0	12,0	52,8	7,0	9,8	0,9
	23	23/10/2018	194,0	112,0	3,0	64,3	7,8	17,6	0,0
	24	13/11/2018	279,0	-	-	124,1	7,7	39,7	1,0
	25	21/11/2018	448,0	252,0	17,0	112,9	7,2	23,9	0,0
	26	27/11/2018	132,0	80,0	7,0	62,0	7,2	16,7	0,9
	27	04/12/2018	171,0	104,0	4,0	51,4	7,2	6,7	5,1
	28	13/12/2018	185,0	120,0	<1	87,3	7,1	53,0	<0,1
	29	19/12/2018	185,0	114,0	<1	78,9	7,0	50,0	<0,1
	30	22/01/2019	387,0	206,0	48,0	92,4	7,4	16,2	0,5
	31	31/01/2019	150,0	52,0	10,0	67,3	8,3	22,1	0,4
	32	04/02/2019	850,0	422,0	161,0	61,2	6,7	13,2	0,4
	33	11/02/2019	358,0	203,0	26,0	70,7	6,5	9,2	0,4
	34	08/03/2019	177,0	98,0	-	91,4	8,5	41,2	0,7
	35	14/03/2019	153,0	112,0	11,0	66,6	7,4	19,5	0,4
	36	20/03/2019	470,0	104,0	24,0	70,9	7,0	23,7	0,4
	37	08/04/2019	1 344,0	967,0	191,0	123,0	7,7	28,4	0,6
	38	15/04/2019	2 042,0	1 440,0	197,0	106,2	7,3	27,6	0,8
	39	25/04/2019	-	-	-	69,7	8,2	19,1	0,6
		Average values	**595**	**359**	**62**	**109**	**8**	**40**	**3**

Table 4: CTIA Raw Sewage Sample Results, Testing for Suitability as Feedstock in Anaerobic Digestion

Sample Number	Sample Date	Nitrate as N (mg/l)	Ammonia (mg/l)	COD (mg/l)	Electrical Conductivity (uS/cm)	Oil and Grease (mg/l)	pH Level	Total Suspended solids (mg/l)
1	02/09/2019	0,38	107,2	620	1680	813	7,34	309
2	16/09/2019	<0,05	201,88	818	1883	93	7,61	382
3	30/09/2019	<0,05	203,79	1040	1992	65	7,72	708
4	15/10/2019	<0,05	179,89	910	1724	<50	7,25	705
5	30/10/2019	<0,05	140,62	963	1454	<50	7,1	716
	Average values	**0,38**	**166,68**	**870,20**	**1 746,60**	**323,67**	**7,40**	**564,00**

When reviewing the sampling results in Tables 3 and 4, the parameters for ADhighlighted in the introduction are largely met with a few deviations that can be controlled. The food waste at KSIA was also sampled for its suitability as feedstock in the AD process (Tables 5 and 6). The food waste, rich in carbon content, can also be fed into the anaerobic digestion of the raw sewage to neutralize certain parameters that are outliers in the raw sewage such as pH Level. Due to lack of results for ORTIA and CTIA food waste and the ORTIA sewage, for the purposes of this pre-feasibility study, we are going to make the reasonable assumption that the parameters of the waste streams are within suitability as feedstock for anaerobic digestion.

Table 5: KSIA Food Waste Types and Area Generation for Analysis as Presented in Table 6

<table>
<tr><th></th><th>Waste Category</th><th>Waste Type</th><th>Waste Generation Geographic Areas</th></tr>
<tr><td rowspan="4">Included</td><td rowspan="3">Wet waste (Organic)</td><td>Left-over food</td><td rowspan="10">Terminal: retail premises, offices, food outlets
Airside: waste from aircraft cleaning and apron activities and other general areas around the apron
Landside: public parking, multi-storey parking, staff parking</td></tr>
<tr><td>Bones from meat</td></tr>
<tr><td>Coffee grounds</td></tr>
<tr><td>Dry waste</td><td>Solid waste from terminal and offices</td></tr>
<tr><td rowspan="6">Excluded</td><td>Hazardous waste</td><td>Galley waste (aircraft kitchens)</td></tr>
<tr><td rowspan="5">Recyclables</td><td>Office paper</td></tr>
<tr><td>Cardboard</td></tr>
<tr><td>Plastic – PET bottles, HD bottles and LD plastic</td></tr>
<tr><td>Cans</td></tr>
<tr><td>Glass bottles</td></tr>
</table>

Table 6: KSIA Food Waste Lab Results, Testing for Suitability as Feedstock in Anaerobic Digestion Process

Sample Number	Date of Sample	Total Mass of Waste Generated on the Day (kg)	COD (mg Oxygen/kg)	Total Organic Carbon (%g/g)	Total Nitrogen (%m/m)	Total Ammonia (mg N/kg)	pH Level @ 25 °C	Wetness (%Water)
1	12/07/2019	332	89779	77	0,87	76	5	56
2	31/07/2019	663,5	41256	97	0,7924	8903	5,6	53
3	02/08/2019	460,5	33267	96	0,6888	8400	3,6	70
4	14/08/2019	682	45000	98	0,26	28	3,3	51
5	16/08/2019	560	50766	88	0,19	72	3,3	91
6	28/08/2019	740	64400	97	1,1	2,8	2,7	74
7	30/08/2019	508	83990	90	1,8	4,5	3,3	65
8	11/09/2019	503	41584	95	1,8	145	3,8	44
9	13/09/2019	512,5	62366	92	2,1	68	3,1	61
10	25/09/2019	358,5	141589	86	1,7	44	3,8	56
11	27/09/2019	505	19107	94	1,8	71	6,5	64
		Average Values	**61191**	**92**	**1,2**	**1619**	**4**	**62**

It can be seen that the food waste material largely meets the minimum conditions for AD. Due to the airports being like mini cities in terms of their activities, it can be assumed that their food waste and sewage will be like that of municipal sewage and food waste. The AD model used for KwaZulu Natal's eThekwini Municipality was run for the airports'works using the input data shown in Table 7. The AD model's expected output of biogas is shown in Table 7.

Table 7: Input parameters and potential quantity of output of biogas

Airport	CoD – Chemical Oxygen Demand (mg/L)	Suspended Solids (mg/L)	PST COD Removal Efficiency (%)	PST Suspended Solids Removal Efficiency (%)	Output of Biogas (m^3/Day)
ORTIA	650	400	30	50	263
CTIA	870	564			188
KSIA	595	359			80
Comment	Domestic sewage is assumed for ORTIA	Domestic sewage is assumed for ORTIA	Process specific	Process specific	Output of anaerobic digestion model done for Durban eThekwini municipal works

If this sewage is put through an AD plant made up of 100m^3 reactors (biodigesters), ORTIA will need approximately 33, CTIA will need 17 and KSIA 11 to process the daily flow as depicted in Table 2. The cost for a 100m^{3}reactor can be seen in Table 8.

Table 8: Cost of a 100m3 Anaerobic Reactor and Plant

Bill of Quantities (100m^3)	Size Specifications	Material	Quantity	Capital Cost (Rands) for a 100m^3 per day System
Steel neck for tank inner	Digester inner (166cm); Digester outer (196cm); height 130cm	Steel mould boards	3	50 220,00 [18]
Steel mould with outer	Digester inner (600cm); outer (640 cm); height, 380cm)	Type 316 steel (stainless steel) mould	3	502 200,00 [19]
Glass Fibre Plastic Gas Collector	Diameter (164cm); height 70cm	Glass Fibre Plastic	3	15 066,00 [20]
Glass Fibre Reinforced Plastic Cover	640cm; (32,17m^2)	Glass Fibre Reinforced Plastic	3	80 778,87 [21]
Steel parts for reinforcement	For between the inner and outer parts of the tank	reinforcement	3	502 200,00 [22]
Biogas purification system	Less than 400m^3/day interface caliber (diameter 50cm) PVC flange; Desulfurizing filler: 200kgs; suitable to install indoor and outdoor		3	251 100,00 [23]
Sewage pump	5,5kW; 60m^3/hr; head 10m		3	15 066,00 [24]
Water pump	3kW; 40m^3/hr; head 13metres		3	3 515,40 [25]
Biogas generator	10kVA		3	50 220,00 [26]
Installation and commissioning	Estimate		10% of cost of plant	147 036,63
Piping and storage	Estimate		5% of cost of plant	73 518,31
TOTAL (ZAR)				**1 690 921,21**

The capital cost estimate for the systems can then be estimated to be as captured in Table 9 and the expected electricity output is given in Table 10.

Table 9: Capital Cost of the Anaerobic Digestion Plants for each Airport

Airport	Number of 100m^3 Anaerobic Digestion Reactors	Plant Supply and Installation (ZAR)
OR Tambo International Airport	33	55 800 399,95
Cape Town International Airport	17	28 745 660,58
King Shaka International Airport	11	18 600 133,32

Table 10: Electricity Produced from Anaerobic Digestion

Airport	Daily Output Biogas (m^3)	Methane Content	Electrical Generator Efficiency	Methane Heating Value (MJ/m^3)	Conversion Factor (1 kWh=3,6MJ)	Daily kWhs
ORTIA	263	0,65	0,38	37,78	3,6	681,73
CTIA	188	0,65	0,38	37,78	3,6	487,32
KSIA	80	0,65	0,38	37,78	3,6	207,37

5. ECONOMIC ANALYSIS

(a) Summary

Airports Company South Africa has an economic modelling department that creates economic models in Excel spreadsheets. The inputs used in the economic model and the financial outputs for the ORTAI, CTIA and KSIA can be seen in Table 11, Table 12, Table 13 and Table 6.

The economic model yields the net present value (NPV), internal rate of return (IRR), nominal payback period and profitability index. The IRR is compared to ACSA's 11,5% weighted average cost of capital (WACC) rate (2020) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2).The IRR is the return (*i* in Equation 2) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index or PI (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to bea good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+i)^t} \quad \text{...Equation 2}$$

Where:

R_t = net cash inflows and outflows during a single period t

i = discount rate or return that could be earned

t = number of time periods

$$PI = \frac{PV\ of\ future\ cash\ flows}{Initial\ Investment} \quad \text{……Equation 3}$$

In summary:

- OR Tambo International Airport – For a 3.3MLAD plant, NPV is ZAR -38.52m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.
- Cape Town International Airport – For a 1.7ML AD plant, the NPV is ZAR -16.29m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.
- King Shaka International Airport – For a 1.1 ML anaerobic digestion plant, the NPV is ZAR -13.13m (negative) which shows that the installation is not feasible. There will be no internal rate of return nor payback during the economic lifespan of the plant.

Table 11: ORTIA Summarized Economic Analysis

Inputs		Output	
Capacity of reactors for anaerobic digestion (m^3)	3300	End of job cost	ZAR71.56m
Capital cost @ 2020	ZAR55 800 400	Net present value	-ZAR38.52m
Electricity production	248 831.31 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.40/kWh	Nominal payback period	No payback
Beneficial operation	2026	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR1 227 609/annum (2020 terms)		

Table 12: CTIA Summarized Economic Analysis

Inputs		Output	
Capacity of reactors for anaerobic digestion (m^3)	1700	End of job cost	ZAR42.8m
Capital cost @ 2020	ZAR28 745 661	Net present value	-ZAR16.29m
Electricity production	177 871.81 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.07/kWh	Nominal payback period	No payback
Beneficial operation	2029	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR632 405/annum (2020 terms)		

Table 13: KSIA Summarized Economic Analysis

Inputs		Output	
Capacity of reactors for anaerobic digestion (m^3)	1100	End of job cost	ZAR23.85m
Capital cost @ 2020	ZAR18 600 133	Net present value	-ZAR13.13m
Electricity production	75 690.13 kWh/annum	Internal rate of return	N/A
Electricity cost	ZAR1.23/kWh	Nominal payback period	No payback
Beneficial operation	2026	Exclusions: Cost of labour and final sludge waste removal (transportation –inbound and outbound), utilities (water and electricity), savings from municipal waste costs, avoidance cost of north and south WWTP disposal and logistics	
Construction period	1 year		
Corporate tax	28%		
Economic lifespan	20 years		
Degradation	0.8% per annum		
Operational and maintenance cost	ZAR409 203/annum (2020 terms)		

The avoidance cost for the operations of KSIA's WWTP have not been considered due to the current plans of the municipality to convert the plant to a pump station that will transfer the sewage to the nearby extended municipal water treatment works. If this condition changes, the model must consider the avoidance cost. The cost of logistics around disposal of sludge etc. have not been considered for the prefeasibility stage. It is important to note that if these costs were taken into consideration, it would not change the result of the business case, but rather provide a stronger "unfeasible" result.

The resulting economic analysis shown in Tables 11, 12 and 13 prove that AD from the sewage produced by the airports is currently not feasible based on electricity generation alone.

(b) Additional Factors to be Considered in the Adoption of Anaerobic Digestion

Upon discussion with the eThekwini Municipality Wastewater department, the volumes of sewage that the airport produces will not make for substantial energy generation. With the lack of environmental penalties and personal responsibility for treating the sewage, it will be cheaper to allow the wastewater to be handled by the relevant municipalities.

If KSIA intended to manage the WWTP permanently, this would make a business case as the logistics for treated effluent release is significantly more than the maintenance and operations of an AD plant. Discussions with Sasol, a giant petrochemicals company, experienced in many types of waste to energy technologies, including AD, revealed that for the waste volumes and the nature of waste produced at the airports, getting one's benefits solely from the energy produced will not make for a viable business case. However, if ACSA had to be held liable for the waste streams, as is the case with Sasol who are not allowed to release their petrochemical waste into natural rivers and streams, using AD and other methods of treating the waste are crucial. It also proves feasible not in terms of energy generation, but in terms of cost avoidance of environmental penalties.

A factor that may cause a difference in the business case is the legislation of the Western Cape government that requires a 50% reduction in food waste to landfill and zero food waste to landfill by 2027 which will attract special disposal costs or penalties. This avoidance cost may make for a feasible business case for Cape Town International Airport.

6. TECHNOLOGY RISK ASSESSMENT

This section looks at the various risks associated with the operations of an onsite AD plant. Table 14 shows the various

technology risks and the possible risk mitigations. The focus is an overview of feedstock level (influent) fluctuations, single point of failure, agility and turn-down ratio.

Table 14

Risk	Description	Possible Mitigation
Insufficient feedstock for upkeep of biogas output or too much feedstock due to water leaks or from a firefighting event	If sewage is limited due to decreased operations of the airport, continuous output of biogas will be interrupted.This will affect the airports' energy mix in that the shortfall must be made up from another energy source. Excess feedstock may result in spillage that will require environmental clean-up.	1. To make up for the shortfall in sewage feedstock, sewage from neighbouring sites or the municipal line could be drawn in.An overflow of sewage could be contained in a designed overflow tank in the case of KSIA and a release into the municipal line in the case of CTIA and ORTIA. An intelligent control system will need to be adopted and prior arrangements secured for the system to mitigate shortfalls and overflows. 2. Alternately a smart electricity grid could be designed to make up for the shortfall and fluctuations in biogas output by load curtailment programmes or prioritization of the use of biogas in the case of above average biogas output.
Single Point of Failure	This is failure at a single point such that without it the entire plant will not be able to operate. For the AD plant, the single point of failure focuses on the case that the AD process is unsuccessful.	1. Electronic monitoring of all critical parameters that are paramount to the success of the AD process and putting in place a record-keeping and early warning systemsarekey to the process control of the system. 2. It is advisable that process control be put in place to ensure that parameters are optimal forAD. 3. Care should be taken to monitor the VFA (volatile Fatty Acids)level as this can raise the pH level and cause digester failure. [27]Appropriate chemical treatments such as lime, soda ash, muriatic acid, etc. should be electronically controlled to avoid failure [28]. 3.A fail-safe mode or default mode should be programmed/hard-wired into the system in case of loss of the control system.
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	1. Working with the influent to ensure the correct organic loading, i.e.,within desired parameters as described in the key parameters for ADforms a critical basis for the control of the ADprocess to respond to increase or decrease in biogas output.
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operations, site demand and maintenance regimes towards cost effectiveness	1. Increase in enzymes can quicken the digestive process in the first stage, hydrolysis. [27] 2. Increase in temperature can increase the rate of digestion, however, this will have to be designed for; thermophilic digesters operate at temperatures higher than ambient (mesophilic digesters). [28]

7. AIRPORTS INTEGRATION STRATEGY

Due to this pre-feasibility study showing that all three installations would be unfeasible, proceeding further with the AD technology must have other motivations. It is advised that for KSIA and CTIA this pre-feasibility study be revised to include all costs and savings that have been excluded:

- KSIA – in the instance that the municipality fails to put in place the additional sewage plant capacity to handle the

airport's sewage volumes, the handling and processing costs of the airport's treated sludge will provide a strong economic case due to the cost savings.

- CTIA – in preparation for the legislation of the Western Cape Government of 50% food waste to landfill by 2025 and zero food waste to landfill by 2027.

The adoption of KSIA's anaerobic digestion plant should focus on upgrading technology and plant equipment of the airport's current South WWTP and include a capture for biogas production and transfer to the CHP plant onsite or if another use is identified, this could be used in a smaller CHP plant.

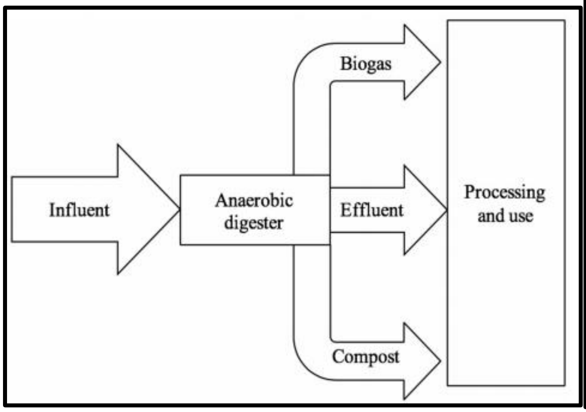
The adoption of AD at CTIA will need an in-depth investigation into waste to energy plants planned or established within a reasonable distance from the airport. The most reasonable economic decision must be made considering the cost to process waste food onsite versus paying for another business to process waste food safely and legally, i.e., in accordance with the Western Cape Government's legislation. Based on the work done for CTIA's and KSIA'sAD plants, learnings can be applied when approaching the furthering of the ADpre-feasibility study.

8. PROPOSED OPERATIONAL PHILOSOPHY

This section describes the proposed operational philosophy that should be considered for an airport environment covering technical, business, operations, and maintenance activities. It would be advisable that the costs for each operational philosophy be firmed up for the next revision of the airports' pre-feasibility studies.

(a)Technical

The proposed technical operating philosophy is described in the context of the inflows and outputs as depicted in figure. 12. The influent is the wastewater at the airports, added to which is the food waste that will enrich the influent and help with organic loading. The influent enters the anaerobic digester. The anaerobic digester set up is shown in figure. 13. Once digested, there are three products as seen in figure. 12that need to be used, i.e. biogas, effluent and compost. The biogas is a useful fuel that can be used as a supplement to the planned natural gas CHP cycle to support the airports' base load energy requirements. The proposed plan is to establish off-takers for the compost such as neighbouring farms. KSIA has many prospective off-takers considering that the area has many sugar-cane farming establishments and other farming activities within a 15km radius. For the other airports, the market for off-takers is yet to be established. The effluent is proposed to be filtered and used for second class water purposes, especially flushing of toilets.



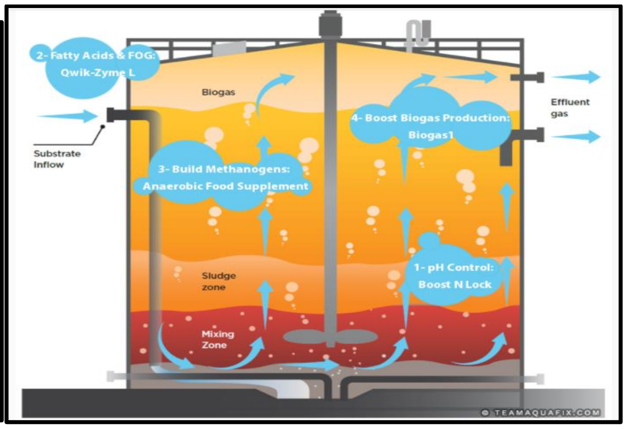


Figure 12: The Anaerobic Influent and output Systems [27] Figure 13: Anaerobic Digester [28].

The reuse of the treated effluent for flushing toilets, which is about the biggest single user of water at airports, could be the game changer that saves costs on potable water and makes the investment feasible.

(b) Plant Operation for Business Continuity and Cost Effectiveness

Due to the international airports (ORTIA, CTIA and KSIA) being investigated for the use of natural gas in a combined heat and power (CHP) cycle to satisfy baseload energy demands and at certain times even the fluctuating energy demand, it is proposed that the biogas produced in the AD process be used as supplemental fuel to the natural gas fuelled CHP cycle. It is not advisable for biogas output to be used as a mainstream fuel or as a stand-alone fuel source for any energy demand, as fluctuations in biogas output and biodigester failure may cost downtime that interrupts airport operations. It is proposed that the treated effluent be used in a closed loop for the flushing of ablution facilities which will be the game changer that makes the AD plants cost effective for the airports. Proper investigation into the risks of using treated effluent for flushing of ablutions including risk mitigation and control measures to ensure that it is safe, must be undertaken. A separate second-class water reticulation line should be established for the flushing of ablution facilities. Should there be an interruption in service from the second-class water reticulation line, the potable water line could provide service.

Off-takers for compost should be established and secured via agreements to ensure that there is a proper income as well as guaranteed removal of compost off-site.

(C) Operations and Maintenance Activities

Maintenance and operations will need to be contracted out as the specialized fields of AD together with associated process controls are not found within ACSA’s expertise, unless ACSA seeks to employ these skills in house. It is also critical that the entire AD process is continuously monitored electronically, the process controlled electronically, and alarms be recorded and transmitted for specific events occurring during operations of the plant. Preventative and condition-based maintenance is proposed to be electronically triggered and monitored.

If the electronic control system is well designed and implemented, it is possible that 24/7 onsite presence may not be needed – it could beremotely controlled and operated, and call-outs be made when special procedures or attention is required.

CONCLUSIONS

Even though all three international airports’ economic models for the AD produce unfeasible results for the FEL2 stage, it is recommended that it betaken to the FEL3 stage for CTIA and KSIA based on the following reasons:

- The impending Western Cape legislation for a 50% reduction in food waste to landfill by 2025 progressing to zero food waste to landfill by 2027.
- The cost of operations of KSIA’s North and South WWTPs are significant and the urgent need to reduce operational cost due to the financial impact of COVID-19 on the airport business.

To prepare for the FEL3 stage, it is recommended that an investigation be under taken to ascertain the possibility and feasibility of supplementing the South WWTP at KSIA to undertake anaerobic digestion on a full scale.

The FEL3 stage should include in its scope of work the investigation into the relationship between the temperature in the biodigester, retention time of the feedstock and biogas production, as well as organic loading rates. The biogas

production models must be programmed for specific conditions prevailing for the airport waste streams. The quantification of effluent and compost should also be included in the model. The investigation into the use of treated effluent for second class water purposes such as flushing of toilets should be included in the study. The investigating of the market for compost off-takers should be undertaken.

In terms of pilot implementation, it is recommended that KSIA be fitted and operated with a packaged biodigester (on a small scale) to understand the challenges and process controls required for anaerobic digestion of the airport's waste streams (sewage and food waste). A small generator should be installed along with the packaged biodigester to produce electricity from the biogas production to run the pumps at the waste-water treatment plant, and thermal harvesting be done to satisfy the thermal energy requirement for AD.

As a result of this pilot implementation, the necessary operational and process flow regimes will be available for further roll-out as needed across the group of airports.

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